NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 953

JUDGMENTS OF RELATIVE MOTION IN TACTICAL DISPLAYS

Supersedes AD-A101 606 MC

by

Kevin LAXAR, Arthur N. BEARE, Reinhard LINDNER, and George MOELLER

Naval Medical Research and Development Command
Research Work Unit MF58.524.004-9021

Released by:
W. C. MILROY, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

31 May 1983

JUDGMENTS OF RELATIVE MOTION IN TACTICAL DISPLAYS

by

Kevin LAXAR, Arthur N. BEARE, Reinhard LINDNER, and George MOELLER

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

Report Number 953

Naval Medical Research and Development Command
Research Work Unit MF58.524.004-9021

Approved and Released by:

W. C. MILROY, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

SUMMARY PAGE

THE PROBLEM

To examine the factors which influence an operator's ability to make judgments about directional relationships depicted in tactical displays.

FINDINGS

Using line of sight diagrams similar to those employed in a submarine attack center, decisions about relative motion were sometimes facilitated when target motion was displayed as bearing to the right. Decision times for one of three tactical geometries, "overleads," were consistently longer than for other tactics.

APPLICATION

This study describes some factors which affect an operator's ability to interpret spatial relationships in displays of fire control and navigation information. Although intensive practice can improve performance on such tasks, operators must be made aware that certain tactical geometries are consistently more difficult to interpret than others.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Naval Medical Research and Development Command Work Unit MF58.524.004-9021 -- Human Information Processing in Submarine Man-Machine System Effectiveness. Previous reports in this series on processing displays are as follows:

NSMRL Report No.	Date
725	August 1972
758	September 1973
760	September 1973
841	January 1979

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

Two experiments examined the response times with which the direction of relative motion could be inferred from tactical "line of sight" diagrams, static displays of target and own ship motion used in solving submarine fire control and navigation problems.

In the first experiment, 12 experienced right-handed naval officers responded more rapidly to displays depicting target motion to the right than to the left, but 12 inexperienced officers, and six left-handers, did not. Overall response times for experienced and inexperienced officers were not reliably different, and practice at the task improved the decision making speed of both groups. The experienced officers, however, performed with consistently greater accuracy.

For all groups, one of the three tactical geometries yielded about one-third longer response times than the others. This was the "overlead" situation, in which own ship's speed across the line of sight exceeds that of the target.

In the second experiment the effect of decision strategy on this "tactic" effect was evaluated with a group of 18 naive subjects. Control of strategy through instruction and order of problem presentation did not reduce the longer response times for overleads, but it did reduce the right-left directional bias related to target motion that was noted in the first experiment.

It was concluded that the directional bias could be eliminated if, in initial training, problems showing a single kind of tactical situation (with an equal number of targets moving toward the right and the left) were grouped together instead of being randomly intermixed.

Since the overlead geometry appears to be more difficult to interpret, as indicated by consistently longer processing times, it was suggested that this tactical situation receive additional attention during training.

Journal of Applied Psychology
1983, Vol 68, No 2, 262-272

Judgments of Relative Motion in Tactical Displays

Kevin Laxar, Arthur N. Beare, Reinhard Lindner, and George Moeller
Naval Submarine Medical Research Laboratory, Groton, Connecticut

Two experiments examined the speed with which the direction of relative motion could be inferred from static tactical displays. In the first experiment, 12 experienced right-handed naval officers responded more rapidly to displays depicting target motion to the right than to the left, but 12 inexperienced officers did not. For both groups, one of the three tactical geometries yielded significantly longer response times than the others (a "tactic" effect). In the second experiment the influence of decision strategy on the tactic effect was evaluated in a group of 18 naive subjects. Control of strategy through instruction and order of problem presentation did not reduce the tactic effect but did interact with the directional bias related to target motion. The tactic effect was discussed in terms of directional incongruity among displayed and inferred stimulus elements. Implications for training are discussed.

Submarine crews often state that certain geometric relationships between the motion of their own ship and a target ship lead to better weapons firing solutions than others. Comprehensive fire control simulations (Moeller, Laxar, Luria, Weitzman, & Engstrand, Note 1) have confirmed that estimates of a target's motion and position may be more accurately or more quickly obtained in certain situations than in others, given about the same quality of information. Two aspects of the situations noted in that report that affect accuracy of target motion analysis are: (a) the direction of motion of each ship toward the right or left, and (b) the kinds of relationship between own ship and target courses.

This research was conducted under the Naval Medical Research and Development Command, U.S. Department of the Navy, Research Work Unit MF58.524.004-9021. The opinions and assertions contained in this article are those of the authors and should not be construed as official or as reflecting the views of the Department of the Navy or the Naval Submarine Medical Research Laboratory.

The authors wish to express their appreciation to the staff and students of the Naval Submarine School, New London, and the members of the Naval Submarine Medical Research Laboratory who served as subjects in these experiments. The assistance of the editor and two anonymous reviewers for their comments on an earlier draft of this article is also gratefully acknowledged.

Requests for reprints should be sent to Kevin Laxar, Behavioral Sciences Department, Naval Submarine Medical Research Laboratory, Box 900, Naval Submarine Base New London, Groton, Connecticut 06349.

Those findings appeared to be related to the contemporaneous findings from studies of human information processing that there are common biases that distort interpretation of directional information, such as with the above–below relationship (Chase & Clark, 1971; Seymour, 1969). Further, Olson and Laxar (1973a, 1973b) found that the term *right* was processed faster than the term *left* in a verification task using abstract word–picture diagrams. Subjects determined if the words *left* or *right*, printed within a square, correctly described the location of a dot appearing to one side or the other of the square. Other investigators have shown that discriminating right from left presents more of a problem for a human decision maker than discriminating other relationships, such as above–below, in both simple displays (Farrell, 1979; Just & Carpenter, 1975; Maki, Grandy, & Hauge, 1979) and in more complex map-reading tasks (Loftus, 1978; Maki, Maki, & Marsh, 1977).

The first Naval Submarine Medical Research Laboratory study in the present series, by Laxar and Olson (1978), set out to determine whether the simulation study (Moeller et al., Note 1) findings regarding right and left represent a special case of the biases noted in the more abstract studies. In their experiment, right–left differences were assessed in the interpretation of naval tactical displays using line of sight (LOS) diagrams (Figure 1) in a verification task. In the ab-

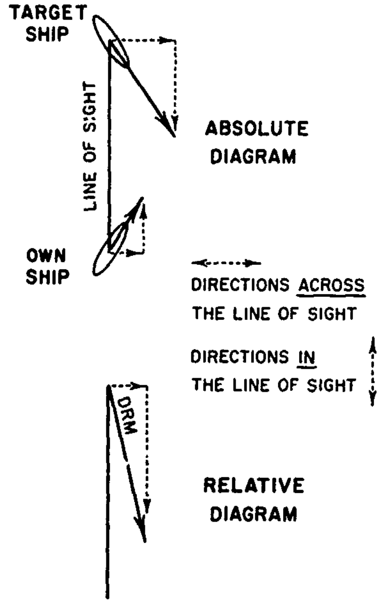

Figure 1. Tactical line-of-sight diagrams. (In the absolute diagram each ship's vector represents its direction and speed with respect to the LOS from own ship to target. The relative diagram is the unique solution representing the target's direction of relative motion with respect to own ship.)

solute or true motion LOS diagram (upper portion of Figure 1), the direction and speed of target and own ship at some instant are represented by the vectors originating from the top and bottom of the line of sight between the two ships. The courses are represented by the direction of the arrows, and the speeds are represented by the length. The components of each ship's vector are speeds in and across the line of sight. By vector subtraction, the relative speeds in and across the line of sight are derived. The resultant vector, the direction of relative motion (DRM), is depicted in the relative LOS diagram (lower portion of Figure 1), and represents the motion of the target ship as it would appear to an observer aboard own ship. These LOS diagrams represent one of a large class of decision aids whereby predictions of future observations are derived from hypotheses made about currently observed components.

Depending upon the geometry, the LOS diagrams represented one of three kinds of tactical situations (Figure 2). In the lead situation, both ships are moving across the line of sight in the same general direction, but the speed of the target across the line is greater; the DRM is in the direction of the target's general heading. In the lag situation, own ship and target are moving across the line of sight in opposite directions; the DRM is again in the direction of the target's motion. In the overlead situation, both are moving in the same general direction but own ship speed across the line of sight is greater; the resulting DRM is in a direction opposite that of either ship's motion. The geometries were chosen to be representative of situations encountered at sea, and the diagrams were constructed so the difference in ship speeds was clearly discriminable visually. These geometries are completely general in that they represent all possible instances in which lateral relative motion is represented.

For each trial in the Laxar and Olson (1978) experiment, the subject was presented with a display consisting of an absolute LOS diagram with a relative diagram below it. His task was to decide as rapidly as possible if the relative diagram correctly described the motion shown in the absolute diagram and to signal by pressing a "true" or "false" key. Experienced submarine officers and inexperienced recent graduates of basic officers' submarine school participated as subjects.

Contrary to the hypothesis, responses to

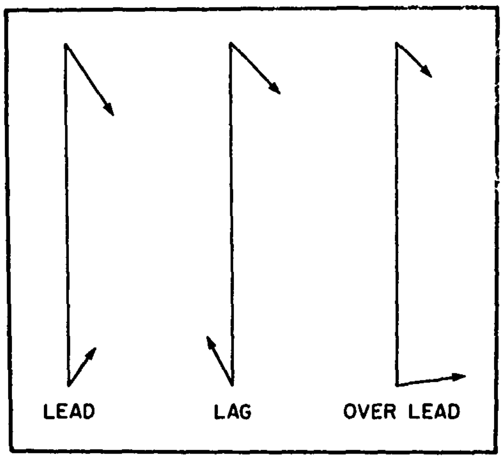

Figure 2. Line-of-sight diagrams showing an example of each of the three tactical geometries used in both experiments. (The lead and lag examples imply relative motion to the right, whereas the overlead case implies relative motion to the left.)

diagrams depicting relative motion to the right were not reliably faster than those showing motion to the left. However, one of the three tactical geometries, overleads, did require significantly more time to interpret than the others. Two other influences were shown to have profound effects on performance. First, in this verification experiment, true decisions were made faster than false ones, as predicted by models of human information processing (Chase & Clark, 1972) and found in previous research (Just & Carpenter, 1975; Olson & Laxar, 1973a, 1973b) using a similar paradigm. Second, a strong effect of stimulus–response (S–R) compatibility (Fitts & Seeger, 1953), often spoken of as control–display correspondence, was found. When stimulus and response were compatible, as when direction of relative motion was to the right and the true button was also on the right, reactions were faster than when stimulus and response were not spatially compatible.

Several research teams (Friedman & Polson, 1980; Simion, Bagnara, Bisiacchi, Roncato, & Umilta, 1980) have noted that the outcomes of studies of right and left direction effects depend heavily on the nature of the stimulus used and the kind of processing required in the task. Review of the magnitudes of the effects of various independent variables in the Laxar and Olson (1978) experiment suggested that the magnitudes of the true–false effect, S–R compatibility, and the tactic effect were so great that they masked the relatively small right–left effect (Broadbent & Gregory, 1965). The first experiment reported here addressed this hypothesis. Subjects were shown only the absolute LOS diagram and asked to indicate directly their judgment of the direction of relative motion. With this paradigm, both the true–false and the S–R compatibility variables were eliminated.

As previously noted, the three types of tactical situations presented to the subjects in the Laxar and Olson (1978) experiment were a major source of variation in subject responses. A second approach, then, to unmasking right–left differences obscured by more powerful effects would be to conduct further studies that minimize the tactic effect. The second experiment reported here was designed to assess the effect of the subject's approach to the task. An attempt was made to manipulate this strategy directly by instruction, and indirectly by presentation of the several geometries separately or intermixed.

Experiment 1

Method

Subjects. Twenty-four male naval officers volunteered to participate in the experiment. Twelve had extensive experience in the use of LOS diagrams and comprised the experienced group. All were serving as instructors at the Naval Submarine School. Their ages ranged from 25 to 40 years (*Mdn* = 31.5), and they averaged 4 years of at-sea experience using LOS diagrams. The inexperienced group was composed of 12 students in the Submarine Officers' Basic Course at the Naval Submarine School. The age range was 22 to 34 years (*Mdn* = 23.0). Men in this group had no practical experience with LOS diagrams but all had recently received several hours of instruction and practice in their use. All subjects were classified as right handers by the Briggs and Nebes (1975) handedness questionnaire, and all had 20/20 visual acuity, with optical correction where necessary.

Task. The subject was presented with an LOS diagram and asked to determine whether the direction of relative motion in the tactical situation depicted was to the right or to the left. No strategy for making the judgments was suggested. Because a pilot study had shown that such latencies were on the order of several hundred milliseconds, a maximum response time of 2.5 sec was permitted and a minimum of 175 msec was set to eliminate false starts.

Stimuli and apparatus. Absolute LOS diagrams showing eight examples of each of the three tactics (four basic diagrams and their mirror images) were used for a total of 24 stimuli. They were presented on the cathode ray tube of a Tektronix 4010 display terminal driven by a Data General NOVA 1220 minicomputer. The program (Olson, Moeller, & Laxar, 1973) was that used for the previous experiment in this series (Laxar & Olson, 1978). It presented blocks of stored stimuli in randomized order and recorded the response times (RTs) to the nearest millisecond. Responses were made by pushing keys at the ends of the bottom row of the terminal's keyboard: "z" for left and "/" for right. When a response was made, the LOS display was erased and a display appeared giving the RT and feedback to the effect that the response was correct, incorrect, too fast, or too slow.

The LOS diagrams appeared centered on the display screen, subtending approximately 15 degrees of visual angle at a viewing distance of 43 cm. The subject sat in a small room, partially isolated from the experimenter. Room lighting was dim (11 lx) in order to minimize reflections from the face of the display screen. The luminance of the displays was 8.6 cd/m², with a brightness contrast of 92%.

Procedure. The subject was told that the purpose of the experiment was to determine how quickly he could make decisions about the spatial relationships among

elements of simple displays. To familiarize him with the task and reduce warm-up effects, he was given two 48-trial blocks of practice stimuli, one consisting of the words *right* or *left*, and the other of a square flanked by a smaller diamond. The subject was to respond by pressing the key indicated by the word displayed or the key on the same side as the diamond. The subject was then given a block of 24 practice trials with the LOS diagrams. After a short break, four blocks of 24 stimuli were presented in a new random order in each block. Each subject was run in a single 1-hour session consisting of the three practice blocks and the experimental LOS trials, for a total of 216 trials per session.

The task was self-paced. The subject initiated each trial by pressing any key on the keyboard. After 1 sec, one of the LOS diagrams appeared on the screen. The subject used the index finger of the appropriate hand to press the right or left key. After a 1-sec interval, the feedback message appeared for several seconds. When it was erased, the terminal was ready for the next trial. The instructions emphasized speed of response while maintaining a high degree of accuracy. However, the subject was told not to worry about erroneous responses as he would be given a second chance at those he had missed. At the conclusion of the session, the subject was given the handedness questionnaire. Results from the practice blocks were discarded, and analysis was performed on the set of 96 correct responses from the LOS task.

Results

In keeping with standard procedure for analyzing reaction time data in information processing tasks (Chase & Clark, 1971; Seymour, 1969; Sternberg, 1969), analyses were computed on the mean, rather than median, latencies for correct responses only.[1] In accord with this same practice, trials on which an error was made were rerun and the error latencies discarded, so that only the total number of errors committed by each subject during his entire experimental session were available for further analysis. This method precluded any detailed analysis of errors or speed–accuracy tradeoffs (Wood & Jennings, 1976). Error rates will, therefore, only be mentioned in passing to help elucidate findings from the RT data.

Examination of the means for the right and left directions of relative motion for the three tactics showed that right was faster than left for both the lead and lag situations, but with overleads, left DRMS were faster than right. As noted above, the overlead tactic is the only one in which the DRM is in the direction opposite that of both target and own ship motions. This led us to examine the right-superiority hypothesis in terms of direction of target motion, rather than direction of relative motion as was done in the preceeding LOS study (Laxar & Olson, 1978). This convention will be used in the analysis of all experiments described in this article, and the results for Experiment 1 are given in these terms in Table 1. Its use changes only the direction effect and its interactions in the analysis. A 1 (between-subjects) × 4 (within-subjects) analysis of variance (ANOVA) was computed using the raw scores. The between-subjects variable compared experience versus inexperience. The within-subjects variables were four blocks of trials, three tactics, four stimuli, and two directions of target motion. Stimulus was included only as a dummy variable for computational convenience in this and subsequent between-subjects analyses.

The right–left directional effect, now expressed in terms of direction of target motion rather than direction of relative motion, was significant, $F(1,\ 22) = 17.25$, $p < .001$. A subsequent ANOVA using direction of relative motion yielded a nonsignificant direction effect but a significant interaction between tactic and DRM, $F(2,\ 44) = 16.19$, $p < .001$. The main effect of blocks of trials was also significant, $F(3,\ 66) = 8.19$, $p < .001$. Although there was no difference between the experienced and inexperienced officers in overall RT, the significant interactions (evident in Figure 3) of the between-subjects variable with block, $F(3, 66) = 3.29$, $p < .05$, and with Block × Tactic, $F(6,\ 132) = 2.26$, $p < .05$, indicate that performance changed with practice in different ways for the two groups.

To obtain a clearer picture of the results, separate within-subjects ANOVAs were computed on the data from the experienced and inexperienced groups. Three variables were investigated in these analyses: blocks of trials, tactics, and direction of target motion. In each block of trials, RTs were averaged over stimuli to yield a single "right" and a single "left" mean score for each tactic. The results are as follows:

[1] In the previous study using these same LOS stimuli (Laxar and Olson, 1978), ANOVAs computed on mean and median RTs yielded virtually identical results. In the present experiment, a high correlation, $r(46) = .94$, $p < .001$, was obtained between the cell means presented in Table 1 and the corresponding medians

Table 1
Response Times (in msec): Experiment 1

Block	Direction of target motion	Experienced officers: Lead	Lag	Overlead	Combined	Inexperienced officers: Lead	Lag	Overlead	Combined
1	Right	585	569	776	664	521	600	710	611
	Left	624	615	887	709	606	561	724	631
	M				676				621
2	Right	534	568	750	617	496	501	662	553
	Left	592	601	882	691	577	531	704	605
	M				654				579
3	Right	483	510	697	563	520	511	650	560
	Left	616	559	713	629	572	562	685	606
	M				596				583
4	Right	467	506	622	532	518	525	679	574
	Left	560	547	671	593	571	509	681	587
	M				562				581
Overall	Right	517	538	711	589	514	534	675	574
	Left	598	580	788	655	581	541	699	607
	M	558	559	750	622	548	538	687	591

1. For both groups, RTs appear to decrease over successive blocks of trials. This effect was significant for the experienced officers, $F(3, 33) = 6.88$, $p < .01$, whose performance improved nearly linearly, but not for the inexperienced officers, $F(3, 33) = 2.67$.

2. The effect of tactical situation was significant for both experienced, $F(2, 22) = 47.21$, $p < .001$, and inexperienced officers,

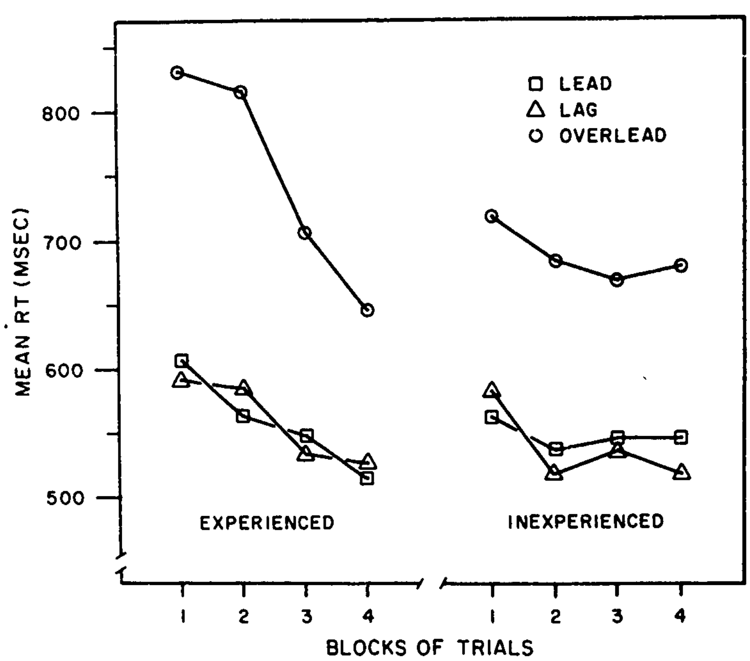

Figure 3 Experiment 1: Mean response times by block for the three tactical geometries.

$F(2, 22) = 23.30$, $p < .001$. The Newman-Keuls procedure confirmed that for both groups overleads gave significantly longer RTs than leads or lags, which did not differ significantly from each other. For the experienced officers, the Block × Tactic interaction was significant, $F(6, 66) = 3.65$, $p < .01$, reflecting the fact that RTs for overleads decreased to a greater extent than RTs for leads and lags. This was not the case for the inexperienced officers, who showed a similar (but nonsignificant) decrease in RT over blocks for all tactics.

3. Direction of target motion was a significant factor in the performance of the experienced officers, where stimuli depicting right-moving targets were responded to faster than those depicting left-moving targets, $F(1, 11) = 19.40$, $p < .01$. Although inexperienced officers responded to right-moving targets faster than to left-moving ones, this difference in RTs was not statistically significant, $F(1, 11) = 3.10$.

Though trials on which the subject made errors were rerun, a count was kept of the total number of errors made by each subject. The inexperienced subjects committed nearly twice as many errors (9.6%) as the experienced subjects (4.9%), $t(22) = 2.43$, $p < .05$.

Experiment 2

It is possible that the differences found between overleads and leads or lags is an artifact of the random mixing of examples of all three geometries. Explanation of the findings on that basis assumes that the subjects use different strategies to evaluate different problem geometries. For example, the simple strategy "respond in the direction of target motion" is effective with both lead and lag tactics but yields incorrect solutions for overleads. Under the assumption of separate strategies, the large RT for overleads would be attributed, at least in part, to the necessity to change strategies when confronted with an overlead. Implicit in this explanation is the further assumption that the subject would always be set to use the lead/lag strategy on the next presentation, which is plausible in the light of the 2:1 ratio of stimuli for which it is appropriate.

Experiment 2 was devised to test the hypothesis that strategy switching was responsible for the differences between overlead and the other tactics. Two means were employed to eliminate the effects of changing strategy as a factor in delay of response. One manipulation called for subjects to judge the direction of relative motion depicted in all LOS diagrams using a single strategy to arrive at their decision. In the other, all examples of a given tactic were presented at one time during half the experimental session. The three types of tactics were mixed, as in previous experiments, for the other half. One group of subjects (mixed first) encountered the mixed-tactic mode first, then the separate-tactic mode. The two modes were presented in the reverse order to a second group (separate first). The subjects' task, the apparatus, and the stimuli were identical to those used in Experiment 1.

Method

Subjects The subjects were 18 male civilians or hospital corpsmen recruited from the staff of the Naval Submarine Medical Research Laboratory. They were randomly assigned to each order condition until both groups had nine subjects. The ages of the mixed-first group ranged from 22 to 50 years ($Mdn = 35$), and those for the separate-first group, 22 to 52 years ($Mdn = 33$) All were classified as right handed and all had 20/20 visual acuity at the 43-cm viewing distance, with optical correction where necessary Although some subjects had a passing acquaintance with the LOS concept, all were classified as inexperienced.

Procedure Subjects were read the instructions used in the previous experiment augmented by a brief explanation of LOS diagrams After the subject indicated he understood the LOS diagrams and the responses he was to make, he was instructed in a strategy that could be used in the solution of all diagrams. The strategy provided was: "Construct an imaginary line straight up from the tip of the own ship vector The DRM is the same as the side of that line on which the tip of the target vector falls."

Each subject was run in a single 50-minute session After receiving the instructions, he was given a practice block of 24 trials in which he saw all stimuli once. Practice RTs were not recorded Each subject was then presented with three contiguous blocks of 24 stimuli, each block composed of all three types of tactic (the mixed condition) and three separate blocks of 24 stimuli, each block composed of a single tactic type (the separate condition) The order in which the three separate blocks of tactics were presented was counterbalanced across subjects, and stimuli were presented in random order within each block.

Results

Results of Experiment 2 are given in Table 2 and Figure 4. The RTs were analyzed in

Table 2
Response Time (in msec), Experiment 2

Mode	Direction of target motion	Mixed-first group: Lead	Lag	Overlead	Combined	Separate-first group: Lead	Lag	Overlead	Combined
Mixed	Right	507	530	705	581	527	488	699	561
	Left	591	581	745	639	555	493	644	563
	M	549	556	725	610	539	491	656	562
Separate	Right	379	416	583	459	506	468	602	525
	Left	397	422	662	494	476	443	616	512
	M	388	419	623	477	491	456	609	518

terms of a six-factor mixed-effects ANOVA. One factor reflected a between-subjects effect (i.e., order; mixed vs. separate tactic given first), and five assessed within-subjects effects (blocks of trials; tactics; stimuli; direction of target motion; and mode of presentation, mixed or separate condition).

There was no reliable difference in overall reaction time between the groups of subjects given the separate or the mixed tactic con-

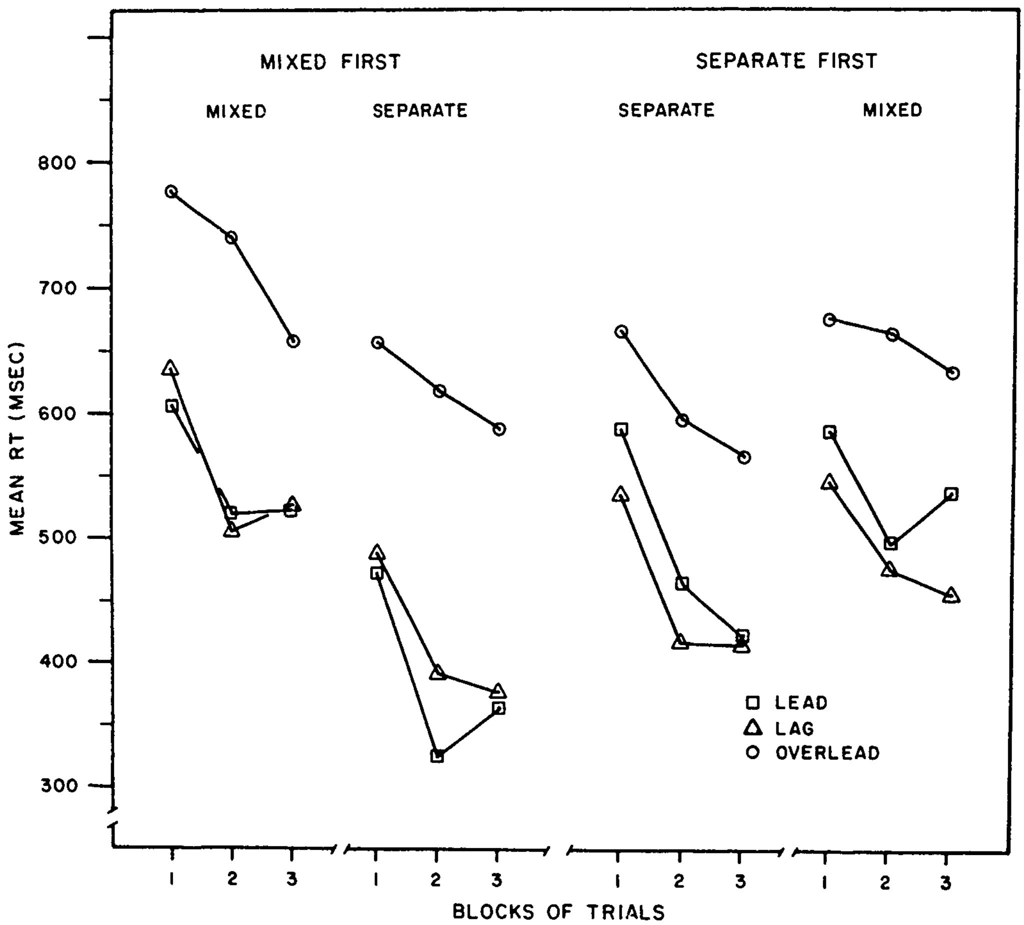

Figure 4 Experiment 2· Mean response times by block for the three tactical geometries.

dition first. Of the within-subjects variables, three of the main effects and several interactions were significant.

1. The blocks effect, $F(2, 32) = 23.80$, $p < .001$, reflects improved performance with practice. As can be seen in Figure 4, this improvement was greatest between the first and second blocks of trials but continued into the third block for each mode of presentation for both orders. The change in performance over blocks was similar to that of the experienced group in Experiment 1.

2. The effect of tactical situation was significant, $F(2, 32) = 28.53$, $p < .001$. Responses to overleads averaged 167 msec longer than did those to leads or lags, which did not differ reliably from one another. This result is identical to that in Experiment 1. The difference between overleads and leads and lags (combined) averaged 196 msec for the mixed-first group and 138 msec for the separate-first group. This difference in tactic effect between groups, as reflected in the Group × Tactic interaction, was not significant.

3. The mode of presentation reliably affected RTs, $F(1, 16) = 21.42$, $p < .01$. Responses under the separate-tactic conditions averaged 89 msec faster than to mixed tactics. The Mode × Order of presentation interaction, $F(1, 16) = 5.47$, $p < .05$, reflects the fact that much of the superiority of the separate-tactic condition is derived from the performance of the mixed-first group. To help clarify this and other interactions, separate within-subjects ANOVAS were computed on the data of the mixed-first and separate-first groups. For the mixed-first group, the separate-tactic condition averaged 133 msec faster than the mixed-tactic condition, $F(1, 8) = 15.06$, $p < .01$. For the separate-first group, overall RTs did not differ significantly between the mixed- and separate-tactic modes. This result is clearly shown in Figure 4.

4. In this experiment, the main effect of direction of target motion was not significant in the between-subjects ANOVA. The direction effect, however, interacted with the order in which conditions were presented, $F(1, 16) = 6.13$, $p < .05$. Subjects given the mixed-tactic condition first responded 47 msec faster overall (mixed and separate conditions combined) to diagrams depicting right-moving targets. This effect was significant in the within-subjects analysis, $F(1, 8) = 6.47$, $p < .05$. Those given the separate-tactic conditions first responded about equally quickly to right- and left-moving targets.

5. The Block × Tactic interaction, $F(4, 64) = 3.50$, $p < .05$, is similar to the Block × Tactic interaction in Experiment 1; RT to overleads showed gradual but continuous improvement over all three blocks, whereas leads and lags improved considerably between Blocks 1 and 2 but were essentially unchanged between Blocks 2 and 3. This interaction did not achieve significance with the reduced degrees of freedom in the within-subjects analyses.

6. There was a significant three-way interaction, Tactic × Direction of Target Motion × Condition, $F(2, 32) = 3.57$, $p < .05$. In the separate-tactic presentations, right-drawing targets were responded to faster than left-drawing ones for overleads, but not for lags and leads. Essentially the reverse was true of the mixed-tactic presentation: right-drawing lead and lag targets yielded faster RTs than left-drawing targets, but this was not true of overleads.

The overall error rate was 9.8%, comparable to that of the inexperienced officers in Experiment 1.

General Discussion

Olson and Laxar (1973a) reported that with abstract word–picture diagrams, verifications involving the word *right* yielded shorter RTs than those involving the word *left*. This asymmetry represents a potentially significant bias in the processing of directional terms. A similar bias did not appear to be operating in the comparison of pairs of relative and absolute LOS diagrams (Laxar & Olson, 1978). Processing the displays in the latter experiment required almost twice as much time (1225 msec) as in the former, and it was thought that the demands of the subject's task may have affected the expression of the directional bias.

Experiment 1 was undertaken to determine if both the directional bias found by Olson and Laxar (1973a) and the unexpectedly large effect of tactical situation found in the Laxar and Olson (1978) study were evident in a task that was both simpler and a closer analog to the actual shipboard interpretation of LOS diagrams. That the task was

less complex is evidenced by the reduction in mean RT of approximately 50% as compared with the Laxar and Olson (1978) verification task. The results suggest that if a bias does exist in the interpretation of tactical displays, it favors response to direction of target motion to the right. This is clear in the case of the experienced officers, where right directions of target motion were signaled 66 msec faster than left. A similar bias is apparent in the data of the inexperienced officers, but the mean difference in reaction time for right versus left is smaller and unreliable. As before, a significant difference in tactical geometry was found.

A difference between the experienced and inexperienced groups in the overlead situation is shown in Figure 3 for right and left directions combined. Inspection of Table 1 indicates that for the first two blocks, the experienced officers had extremely long latencies to left overleads, which contributed greatly to the directional effect obtained. In contrast, the inexperienced group showed a rather uniform difference between right and left geometries in all cases. Since the experienced group made many fewer errors, the two groups may have traded off speed versus accuracy in different ways. As noted previously, the available data do not permit an error analysis by blocks, but it is apparent from the RTs that the experienced group performed more cautiously, especially during the first half of the experiment, thus producing fewer errors. This difference in performance may be partly a result of the age difference between the two groups, but may also be due to a realization by the experienced officers that certain geometries require greater care in interpreting. Although the experienced officers' latencies for the overlead tactic appear unusual, this does not affect the main finding that this geometry is more difficult to interpret.

In Experiment 2, the mixed-first group gave evidence of a directional bias of the same nature and magnitude as that shown by the experienced officers in Experiment 1. Apparently the learning effects in this task were diferent if subjects experienced the separate presentation first, rather than the mixed presentation first (cf. Poulton, 1973). These results are in keeping with the conclusion that the appearance of directional biases is highly dependent on the specific nature of the task at hand (Just & Carpenter, 1975; Laxar, 1979).

The effect of tactical situation was consistently large under all conditions investigated. Overlead stimuli required about 170 msec longer to respond to than leads or lags, which were not reliably different from each other. The manipulations of Experiment 2, which were intended to eliminate the effects of strategy switching, did not significantly reduce this difference. This result ruled out strategy switching as a major contributor to the longer RTs for overleads but was still consistent with the earlier explanation of Laxar and Olson (1978), which attributed the difference to stimulus incongruity (Banks, Clark, & Lucy, 1975; Clark & Brownell, 1975), where various parts of the stimulus complex lack directional similarity. In the present experiments, the subject's task was to determine whether the direction of relative motion was to the left or the right. This situation differs in one important respect from other experiments where congruity effects are present: the task-relevant attribute is not physically present in the stimulus but must be deduced from the relation between the own-ship and target vectors in the LOS diagram. The direction of each of the vectors must be encoded before the DRM can be derived, and these directions are in some cases incongruous attributes of the stimuli; that is, the directions of the vectors in the diagram may interfere with deriving the DRM.

It appears that one vector, in particular, accounts for the assumed interference. For lead diagrams, both the own-ship and target vectors point in the same direction as the DRM; the directional components of both vectors are therefore congruent with that of the correct response. For lags, the own-ship vector is incongruent with the DRM, whereas the target vector is congruent. If the own-ship vector were a significant source of interference, responses to lags would be slower than responses to leads, but this is clearly not the case. For overleads, both own-ship and target vectors are incongruent with the DRM, and the response times are significantly longer. Thus it would seem that the incongruity of the target vector alone is responsible for the

longer processing time associated with overleads.

This argument represents a refinement of that in Laxar and Olson (1978), in which a lack of congruity was proposed as the source of greater processing time in the overlead diagram. The present study suggests that this incongruity lies within the difference between the target and the DRM vectors. The data obtained in Experiment 2 clearly show that the hypothesis of a tactic effect due to a strategy shift is untenable. Apparently the subject uses the own-ship vector as a reference from which to compute the target's relative motion vector, and the discrepancy between the target vector and the perceived DRM leads to the delay in response.

In summary, these experiments are further illustrations of subjects' biases in relative motion situations. In a dynamic highway task, for example, Evans and Rothery (1974) found that, when following another vehicle at a constant distance, drivers perceive the distance as decreasing. Other investigators have found that distances and directions of movements along the line of sight affect the perception of relative motion in dynamic displays (Gogel, 1974; Harvey & Michon, 1974). In the present context, a directional bias, in which stimuli depicting target motion to the right were processed more rapidly than those showing motion to the left, was observed under some of the conditions in these experiments. This effect was elusive and, where present, was small compared to the effect of tactical situation. Further research is required to determine what aspects of the stimulus, task, or the subject's problem-solving set caused this directional bias to appear in some of the conditions of these experiments but not in others. These studies have shown that a particular tactical geometry is not associated with the right-left bias. The results of Experiment 2 suggest that this bias can be effectively eliminated if, in initial training, problems showing a single kind of tactical situation (with an equal number of cases to the right and to the left) are grouped together instead of being randomly intermixed.

This research has also provided further evidence that certain displays of motion may present interpretation difficulties. In a similar context, Bryan (1957) found that the accuracy of motion estimates was affected by S-R compatibility in a manner that paralleled the Laxar and Olson (1978) findings. The present experiments have reaffirmed that overlead situations are more difficult to interpret, as they consistently took longer to process than leads or lags. Given that all types of geometries are important in submarine fire control, especially in certain maneuvers performed to calculate target range, it seems obvious that overlead geometries should be given additional practice in training sessions. Although practice at the specific task involved here generally improved performance, it cannot be concluded that the difference found with overleads would be completely eliminated. The principal value of increased exposure would be to promote awareness that some situations are more difficult to interpret and should be approached with care, a conclusion that may well be applied to other relative motion tasks such as tracking, vehicle control, and air traffic control.

Reference Note

1. Moeller, G., Laxar, K., Luria, S. M., Weitzman, D. O., & Engstrand, R. D. *A study of human factors and their relationships to weapon system effectiveness in submarine and antisubmarine warfare I Graphic methods for target motion analysis (U)* (Report No. 722, Confidential). Groton, Conn. Naval Submarine Medical Research Laboratory, 1972

References

Banks, W. P Clark, H H., & Lucy, P. The locus of the semantic congruity effect in comparative judgments *Journal of Experimental Psychology: Human Perception and Performance*, 1975, *104*, 35–47.

Briggs, G G., & Nebes, R. D. Patterns of hand preference in a student population. *Cortex*, 1975, *11*, 230–238.

Broadbent, D. E., & Gregory, M. On the interaction of S-R compatibility with other variables affecting reaction time. *British Journal of Psychology*, 1965, *56*, 61–67.

Bryan, G L. *A study of relationships between true and relative motion as perceptual tasks in two display contexts* (Tech. Rep. No. 20). Los Angeles: Department of Psychology, University of Southern California, May 1957. (NTIS No. AD-132 743)

Chase, W. G., & Clark, H. H. Semantics and the perception of verticality. *British Journal of Psychology*, 1971, *62*, 311–326.

Chase, W. G., & Clark, H. H. Mental operations in the comparison of sentences and pictures In L. Gregg (Ed), *Cognition in learning and memory* New York: Wiley, 1972.

Clark, H H., & Brownell, H. H. Judging up and down.

Journal of Experimental Psychology: Human Perception and Performance, 1975, *1*, 339–352.

Evans, L., & Rothery, R. Detection of the sign of relative motion when following a vehicle. *Human Factors*, 1974, *16*, 161–173.

Farrell, W. S., Jr. Coding of left and right. *Journal of Experimental Psychology: Human Perception and Performance*, 1979, *5*, 42–51.

Fitts, P. M., & Seeger, C. M. S–R compatibility: Spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology*, 1953, *46*, 199–210.

Friedman, A., & Polson, M. C. *Resource allocation in cerebral specialization* (ISIB Tech. Rep. No. 93). Boulder, Colo.: Institute for the Study of Intellectual Behavior, January 1980. (NTIS No. AD-A082-543)

Gogel, W. C. Relative motion and the adjacency principle. *Quarterly Journal of Experimental Psychology*, 1974, *26*, 425–437.

Harvey, L. O., Jr., & Michon, J. A. Detectability of relative motion as a function of exposure duration, angular separation, and background. *Journal of Experimental Psychology*, 1974, *103*, 317–325.

Just, M. A., & Carpenter, P. A. The semantics of locative information in pictures and mental images. *British Journal of Psychology*, 1975, *66*, 427–441.

Laxar, K. Compatibility and laterality effects in directional information displays. In C. K. Bensel (Ed.), *Proceedings of the Human Factors Society 23rd Annual Meeting*, 1979, 433–437.

Laxar, K., & Olson, G. M. Human information processing in navigational displays. *Journal of Applied Psychology*, 1978, *63*, 734–740.

Loftus, G. R. Comprehending compass directions. *Memory and Cognition*, 1978, *6*, 416–422.

Maki, R. H., Grandy, C. A., & Hauge, G. Why is telling right from left more difficult than telling above from below? *Journal of Experimental Psychology: Human Perception and Performance*, 1979, *5*, 52–67.

Maki, R. H., Maki, W. S., & Marsh, L. G. Processing locational and orientational information. *Memory and Cognition*, 1977, *5*, 602–612.

Olson, G. M., & Laxar, K. Asymmetries in processing the terms "right" and "left." *Journal of Experimental Psychology*, 1973, *100*, 284–290. (a)

Olson, G. M., & Laxar, K. *Speed of comprehending submarine fire control displays: II. Further evidence of right-left differences* (Rep. No. 758). Groton, Conn.: Naval Submarine Medical Research Laboratory, September 1973. (NTIS No. AD-775 827) (b)

Olson, G. M., Moeller, G., & Laxar, K. *RTLAB: A reaction-time laboratory for the Data General NOVA minicomputer* (Rep. No. 748). Groton, Conn.: Naval Submarine Medical Research Laboratory, August 1973. (NTIS No. AD-780 216)

Poulton, E. C. Unwanted range effects from using within-subjects experimental designs. *Psychological Bulletin*, 1973, *80*, 113–121.

Seymour, P. H. K. Response latencies in judgments of spatial location. *British Journal of Psychology*, 1969, *60*, 31–39.

Simion, F., Bagnara, S., Bisiacci, P., Roncato, S., & Umiltà, C. Laterality effects, levels of processing, and stimulus properties. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, *6*, 184–195.

Sternberg, S. The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (Ed.), *Attention and Performance II*. Amsterdam: North-Holland, 1969 (Reprinted from *Acta Psychologica*, 1969, *30*.)

Wood, C. C., & Jennings, J. R. Speed–accuracy tradeoff functions in choice reaction time: Experimental designs and computational procedures. *Perception & Psychophysics*, 1976, *19*, 92–101.

Received July 13, 1982
Revision received November 16, 1982 ■

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSMRL Rpt.#953	2. GOVT ACCESSION NO. AD-A129 722	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) JUDGMENTS OF RELATIVE MOTION IN TACTICAL DISPLAYS		5. TYPE OF REPORT & PERIOD COVERED Interim report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kevin LAXAR, Arthur N. BEARE, Reinhard LINDNER, and George MOELLER		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Submarine Medical Research Laboratory Box 900 Naval Submarine Base New London Groton, Connecticut 06349		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MF58.524.004-9021
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research and Development Command Naval Medical Command, National Capital Region Bethesda, Maryland 20014		12. REPORT DATE 31 May 1983
		13. NUMBER OF PAGES 20
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Right-left
Human Information Processing
Choice Reaction Time
Spatial Directions
Submarines
Visual Displays
Laterality

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two experiments examined the response times with which the direction of relative motion could be inferred from tactical "line of sight" diagrams, static displays of target and own ship motion used in solving submarine fire control and navigation problems.

In the first experiment, 12 experienced right-handed naval officers responded more rapidly to displays depicting target motion to the right than to the left, but 12 inexperienced officers, and six left-handers, did not. Overall

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

response times for experienced and inexperienced officers were not reliably different, and practice at the task improved the decision making speed of both groups. The experienced officers, however, performed with consistently greater accuracy.

For all groups, one of the three tactical geometries yielded about one-third longer response times than the others. This was the "overlead" situation, in which own ship's speed across the line of sight exceeds that of the target.

In the second experiment the effect of decision strategy on this "tactic" effect was evaluated with a group of 18 naive subjects. Control of strategy through instruction and order of problem presentation did not reduce the longer response times for overleads, but it did reduce the right-left directional bias related to target motion that was noted in the first experiment.

It was concluded that the directional bias could be eliminated if, in initial training, problems showing a single kind of tactical situation (with an equal number of targets moving toward the right and the left) were grouped together instead of being randomly intermixed.

Since the overlead geometry appears to be more difficult to interpret, as indicated by consistently longer processing times, it was suggested that this tactical situation receive additional attention during training.